Energy Management Systems for PV Hybrid Systems

- Classification, Structures and Optimisation -

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Abstract

This paper presents a classification of energy management systems (EMS), in order to work out differentiated realization possibilities with detailed characteristics for further discussions and development strategies, with a special focus on optimisation purposes. A short overview of the state of the art is used to point out the pro and cons of the methods used for control and management systems, especially for PV energy supply systems with a high portion of renewable energy converter. This comparison allows to work out the essential characteristics with a focus on their capabilities for a usage in renewable PV energy hybrid systems, especially with respect to the stochastically behaviour of some converter as well as the consumer. Basing on this, the authors present a worked out proposal for a generalized formulation of the structure of such energy management systems, followed by detailed explanations and discussions. This structure could be a helpful tool for future developments and perhaps gives the chance for common discussion standards. The basic structure of the presented EMS consists of three important modules, the prognostic-module, the optimisation-module and the load-management-module, which are also classified in detail.

A very important aspect concerning EMS is the stochastically behaviour of the renewable converter, like PV and Wind Energy converter, as well as of the consumer. This is a really complex and difficult challenge for an optimisation module. For this purpose, mathematical strategies for the modelling of the physical and technical functions of PV-hybrid systems have to be combined with mathematical optimisation algorithms in a very special way. One of the primary questions is the formulation of an effective objective function, in order to guarantee real 'sustainability', especially with respect to the usage of available biomass to avoid local desertification.

PV Hybrid Systems

The following figure shows the fundamental scheme of a PV Hybrid System for modelling purposes [5]. This scheme is a valuable description to develop mathematical formulations in order to get dimension criteria as well as objective functions for optimisation strategies. This scheme is characterised by the three columns converter, storage and consumer, and three rows mainly for electrical energy, thermal energy and material flow. A sufficient dimensioning of the energy storages, especially for electrical energy has a significant influence of the sizing of the converter and therefore on the costs of the whole system. A first step of optimisation may be for this reason the integration of electric vehicles as consumer as well as storage components in a bi-directional manner [1], [2]. Additionally, the equalised power conversion with the combination of wind and solar energy minimises the required capacity of storage batteries.

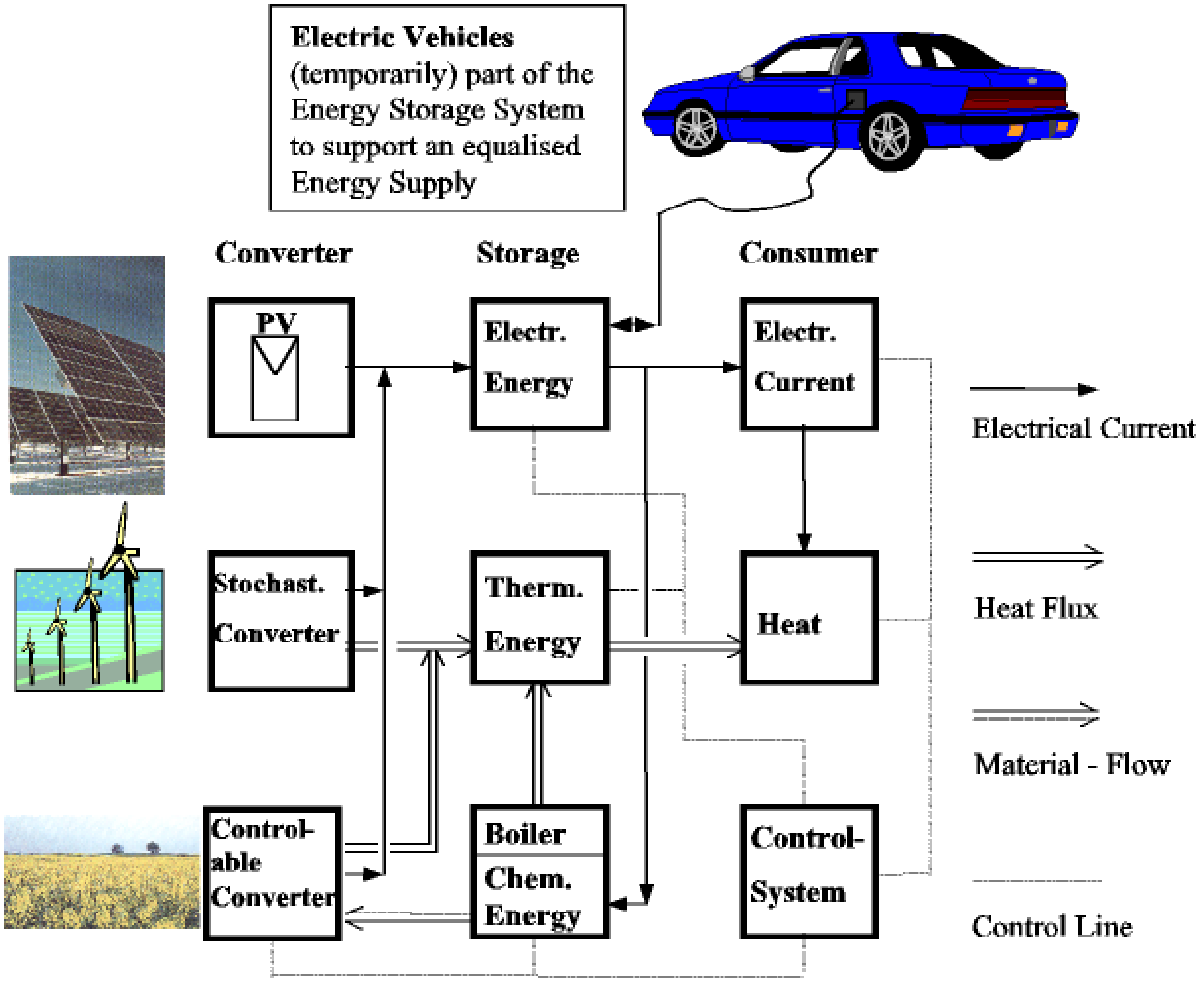

Figure 1: Structure of hybrid systems with electric vehicles [1], [2]

Basic Structure of an EMS for Renewable Energy Systems

Basing on the scheme in figure 1 for PV Hybrid Systems it is possible to develop a principal structure for intelligent EMS [3], [8], as demonstrated in figure 2.

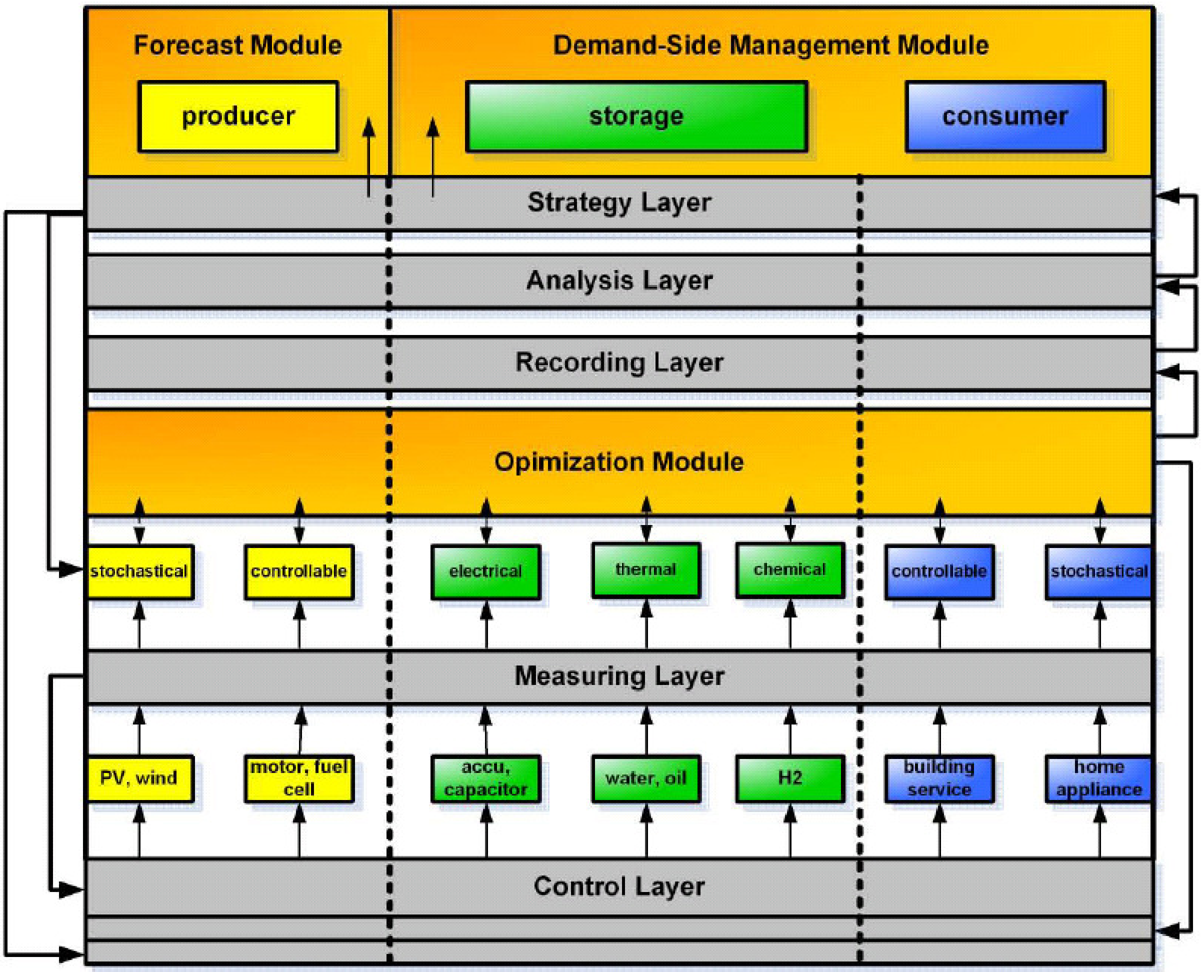

Figure 2: Layout of the EMS-Design [3], [8]

In conventional system management strategies for hybrid energy systems a present optimisation is realized by the measurement of relevant values. The operation of controllable energy generators, the charge of the battery as well as the connection of renewable generators are effected by ideal values, by rules of thumb or by a limit value regulation considering interior factors. The points of connecting and disconnecting the consumer load are set at a certain percentage system load against battery state of charge, battery voltage, line frequency, capacity-frequency-characteristic curves, and load of the diesel generator or periodic specified point of time.

At the simple management strategies usually consumers are not included in EMS. Information about future energy flows are not included in easy control strategies. This deficit makes it understandable that a new kind of EMS has to accomplish further requirements in comparison to conventional system management strategies.

The basic structure of the presented EMS consists of three important modules, the forecast-module (FM), the optimisation-module (OM) and the demand-side management-module (DSM), which are also classified in detail. All three modules can be considered and classified in different detailed levels. The forecast-module generates the future schedule of potential energy production of the renewable energy generators (solar and wind energy). The forecast-module can be built on in different ways. Three basic types are differentiated and presented precisely. The main task of the EMS is to improve the operation of the energy system. The classification of different EMS depends substantially on the functionality of the optimisation-module. According to this the objective function and side conditions of the optimisation task (OT), the optimisation process, the length of the optimisation interval and the structure of the optimisation process can be distinguished. In off-grid PV energy systems with a high portion of renewable energies the task of DSM is an adequate adjustment of the power consumption to the power production. Three different types can be differentiated and are presented in detail: directional, automatically bi-directional and interactive bi-directional demand-side management.

Forecast Module

The forecast-module generates the future schedule of potential energy production of renewable energy generators (solar and wind energy). But these forecasts are afflicted with inaccuracies, which depend on different boundary conditions and can be changed in the course of time (behaviour of solar radiation or wind speed). Controlling the system components of the hybrid system, it is necessary to know these inaccuracies. The FM can be built on in different ways. Data origin plays a decisive role for determining the required forecast method, the length of the forecast interval, the achievable forecast horizon, the required hardware, costs and the forecast accuracy. Three basic types can be differentiated according to data origin: the first type is based on measured data of produced power, the second type is based on internal and external weather forecasts and the third type describes a combination of the both mentioned types. A combination of power measurements with internal and external weather forecasts leads to further additional possible functionalities.

Optimisation-Module

The main task of the EMS is to improve the operation of the energy system. The classification of different EMS depends substantially on the functionality of the optimisation-module. According to this, the objective function and side conditions of the optimisation task (OT), the optimisation procedure, the length of the optimisation interval and the structure of the optimisation process can be distinguished.

Generally the optimisation task can have different objective functions and side conditions. As objective functions can be seen the security of supply, the total costs, the total efficiency or the emissions. Side conditions can be avoidance of unnecessary operation hours, nominal system operation, minimization of battery load, operating the system with maximal efficiency, maximal use of renewable energies, minimal use of controllable power generators and avoidance of losses through unnecessary energy flow through the battery or minimization of output surpluses.

Unfortunately, the above mentioned optimisation criteria are often of contrary nature. For example, the minimisation of the CO_2-Emissions is not necessarily compatible to a minimisation of the operation costs.

For this reason, the best choice would be a multiple-criteria optimisation (MCDM: Multiple Criteria Decision Making). The MCDM-Modelling is characterised by the assumption, that many decisions have to be done with respect to many different criteria, which may in some cases represent contrarily targets. For MCDM-problems [7] there exist the following statements:

If $A \neq \varnothing$ is a set of alternatives (also called actions, strategies or possible solutions) of a decision problem. The function $f: A \rightarrow R^q$, $q \geq 2$, be a multiple criteria evaluation function. The single functions $f_k: A \rightarrow R$ with $f_k(a) = z_k$ ($k \in \{1,...,q\}, a \in A$), and $f(a) = (z_1,...,z_q)$, are called criteria (or targets or attributes). The objective functions f_k are to be minimised. In the case of a maximisation of a criteria $f_k^{'}$, it is possible to define alternatively $f_k = -f_k^{'}$. (A, f) is than a formulation of a MCDM-problem. A MCDM-problem $P = (A, f)$ is defined as multiple objective decision making (MODM)-problem, if the set A can be formulated as $A \subset R^n, A = \{a \in R^n : g_i(a) \leq 0, i \in \{1,...,m\}\}$ for functions (constraints) $g_i: R^n \rightarrow R$. The problem P is often named as vector optimisation-problem (VO-Problem).

One of the most important development tasks for the design of the optimisation module is therefore the search for a useful and effective objective function vector, followed by the next research problem to find a mathematical algorithm to find the solutions of such problems. The numerical calculations for the optimisation have also to be done in an acceptable time interval with respect to the different dynamic operation behaviours of the single converter and components as well as the complete hybrid system as a unit. The optimisation interval complies with the available data from the forecast-module and the demand site management-module. Regarding the time horizon the present optimisation and future-oriented optimisation can be differed.

To classify the optimisation process, several layers have been developed, interacting with the three modules and the systems components. Some layers are essential for each kind of EMS like measuring layer and control layer. To enlarge the functionality of EMS and integrating future events of producer and consumer a model layer and a recording layer are added. In case of self-learning and self-diagnostic features, the EMS is equipped with an analysis layer and a strategy layer [3].

Demand Side Module

In decentralised energy systems with a high portion of renewable energies the target of the DSM is an adequate adjustment of power consumption to the power production. With an increase in stochastically power generators (PV and wind energy) the power production becomes more fluctuant. However, to reach a well adjustment and to guarantee security of supply, there are different options to build on the DSM. Three different types can be differentiated: directional, automatically bi-directional and interactive bi-directional demand-side management.

In the case of directional demand-side management, the available energy is distributed to the consumer without sending a demand feedback signal to the OM. That means there is no forecast of energy consumption. Bi-directional demand-side management uses predictions of energy consumption. The results of this prediction are embedded in the optimisation process. So there is a feedback of the DSM to the optimisation-module. An interactive demand-side management allows the integration of user-specific wishes during system operation. A display can be used to inform the user about the current operating status. In form of a days' or weeks' schedule the user determines his individual consumption e.g. for the home appliances. The individual wishes get checked on reliability with data of the forecast-module, the capacities of storages and the data of other consumer groups. After that, the EMS informs the user about the efforts to realize his wishes. E.g. start of a motor and thus higher cost of operation. This result can be confirmed by the user or another schedule is created.

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